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Consumer Interest Rate and Noise Shocks in Monetary Policy

Rodrigo Duarte Barrela

Student no. 3684 / 23783

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Abstract

The present paper analyzes the differences between shocks to the monetary policy and the consumer interest rates in a context without perfect information where the agents observe only a noisy signal on their interest rate, thus resorting to a signal extraction problem before making their consumption decisions. The results show that non-monetary policy rate shocks – here designated as transmission mechanism shocks – are more important in determining economic fluctuations *vis-à-vis* monetary policy shocks. Noise is not impactful, thus not very important in determining consumers's decisions. The results call for policymakers' special attention when designing macroprudential policies that affect the transmission mechanism of interest rates.

Keywords: Monetary Policy; Noise Shocks; Signal Extraction; Transmission Mechanism

1 Introduction

Economic theory has, by now, figured that monetary policy is key in determining consumption and investment patterns, since agents take into account the interest rate set by the monetary authorities on which their decisions are based. Countless researchers have tried to estimate the effects of monetary policy shocks on the economy using a myriad of different techniques. The conclusions of these studies have been variant over time and the methodologies confronted and criticized for not being able to capture true monetary policy innovations. For instance, in Ramey, 2016, the author states that "true monetary policy shocks are now rare" and even concludes that it may be impossible to distinguish them from information or noise shocks with the current predominant methodologies.

The present paper tries to address this issue by defining the relevant consumer interest rate as the rate that consumers assume in their economic decisions, which is not necessarily equal to the monetary policy interest. A potential divergence between these two rates is attributed to failures (or shocks) in the transmission mechanism.

The inclusion of financial market frictions in macroeconomic models is becoming more relevant in today's paradigm, especially in the wake of the recent financial crisis. Thus, by assuming that the consumers' interest rate is responsive to these frictions, this research expects to contribute to the improvement of macroeconomic modeling. The results show that in a simple New-Keynesian model in which consumers do not perfectly observe their relevant interest rate, monetary policy shocks are less important in determining economic fluctuations *vis-à-vis* transmission mechanism shocks. In fact, some economic variables seem to have a significant response to the latter shocks in the very-short term.

The problem of monetary policy shocks identification and fundamentalness will also be addressed, following the work of Leeper, Walker, and Yang, 2013, who point out that, in the context of fiscal policy, foresight is fulcral to consumers' decisions but also difficults the job of econometricians. Leeper *et al.* show that consumers have information available to them at the time of their decisions that we, as econometricians, do not have access to, something transversal to the field of monetary policy. This caveat induces a need to correctly specify the consumers' information structure when performing VAR estimations. Thus, to tackle this issue, this paper follows closely the methodology in Blanchard, L'Huillier, and Lorenzoni, 2013, introducing an informational friction in the form of a noise shock in the consumer interest rate that does not allow for the agents to distinguish between "good" and "bad" information, thus having to solve a signal extraction problem to be able to make sound consumption choices. However, the findings suggest that these types of shocks are close to meaningless in their impact on aggregate variables. Nonetheless, their modeling is important if we believe that the correct informational structure is the one presented.

The remainder of the paper is divided in the following way: section 2 reviews the literature regarding monetary policy shocks, the transmission mechanism and noise shocks; section 3 presents the proposed models, first with a simple model of unobservable interest rate in section 3.1, and then a more complex model with noise in section 3.2; section 4 presents some concluding remarks, policy implications and ideas to be further explored.

2 Literature Review

To begin studying the effects of monetary policy shocks as opposed to monetary policy rules, one first needs to define them to better understand what will be analyzed. According to Hamilton, 1997, an innovation in monetary policy can be defined as a change in the policy variable induced by the monetary authority that could have been anticipated with knowledge of earlier information. This definition is broad, as there may be various causes for why this happens, but it shows how monetary policy shocks result from informational asymmetries between consumers and the central bank. Hamilton also relates these shocks with measurement errors in the variables that affect the decision-making process, such as output and inflation. In a similar vein, Christiano, Eichenbaum, and Evans, 1999, give three possible explanations for what represents a monetary policy shock. These can be either exogenous shocks to the preferences of the monetary authority, actions taken to avoid the social costs of disappointing private agents' expectations, or simply measurement errors, similarly to Hamilton's view.

Christiano, Eichenbaum and Evans also survey the effects of monetary policy innovations in the economy. In general terms, under recursive schemes for identification, a contractionary interest rate shock leads aggregate output and prices to fall, with the former presenting a hump-shaped behavior, and the latter being late to respond. However, most of these papers studied the effect of unexpected monetary policy shocks using mostly VAR models to estimate impulse responses and identify shocks. In recent years, literature has followed the work of Christiano, Eichenbaum, and Evans, 2005, and Smets and Wouters, 2003, turning to micro-founded general equilibrium models that were able to simulate the response of the whole economy to monetary policy shocks to aggregate economic variables. Most of the latest findings corroborate the negative impact of a contractionary monetary innovation on output, even though they point out that these effects are small and tend to be short-lived.

More recently, Ramey, 2016, builds on the work of Christiano, Eichenbaum, and Evans, 1999, and surveys the latest research on the effects of monetary policy in aggregate variables. Interestingly, the author finds very inconclusive results, arguing that nowadays it is very difficult to identify unexpected monetary policy shocks due to the high degree of transparency of central banks and the systematic nature of today's monetary policy settings. The author even argues that what we are identifying as monetary policy shocks can well be, in fact, just expectations and noise shocks. This can be a problem in econometric terms, as the difference in informational structures between the agents and the econometrician can mean that, when estimating monetary policy shocks, the identified shocks are, in fact, non-fundamental. This result was studied in more detail in Leeper, Walker, and Yang, 2013, for the case of fiscal policy, but can also be applied to a monetary policy setting. This narrative of non-fundamentalness and informational asymmetries will be explored by assuming that households do not perfectly observe their relevant interest rate, having to make decisions based on noisy signals, instead. In this sense, it is also important to understand the literature around noise innovations and how to model them.

Lorenzoni, 2009, studies the effect of technological shocks and their impact on consumers' expectations of long-run variables, such as productivity. In his paper, the noise arises from an environment where consumers have access to public information, but this information can either be noisy or not perfectly reflect the future state of the economy. This is of especial interest given the goal of this paper, in the sense that it provides some guidance as how to think of noise shocks and how to model their effect in the economy. Another interesting result on role of information and expectations comes from Morris and Shin, 2002, who argue that agents tend to overreact to public information, which magnifies the effects of noise shocks. Sims, 2003, shows that imperfect information frictions can lead to different economic outcomes because, when faced with such frictions, economic agents will not behave according to fundamentals. More recently, Blanchard, L'Huillier, and Lorenzoni, 2013, escalated the discussion on the effects of information and expectations. They used both a simple model and a medium-scaled DSGE to identify the effects of noise shocks in productivity by assuming that agents observe technological shocks but cannot observe if these are permanent or temporary, making their decisions based on a noisy signal for the permanent component. This paper follows closely the methodology in Blanchard *et al.*, which will serve as the main reference for the model presented.

Coupled with the theories of informational frictions and noise is the idea that the information used by consumers comes not solely from unexpected monetary innovations but also from other transmission channels, which leads the consumers' real interest rate to differ from the observed monetary policy instruments. Monetary policy changes affect the interest rate relevant to the consumer, which in turn will affect how the agents decide between consumption and savings. Classical economic theory argues that an increase in the monetary rate can lead to lower consumption today due to the higher return on savings (intertemporal substitution effect) or from the fact that higher rates of interest depreciate the price of assets (wealth effect); but theory also tells us that a monetary policy contraction can lead to an increase in disposable income, which in turn leads to higher consumption today (income effect). From these three channels, the predominant one will dictate how a monetary policy contraction affects consumption.

While these transmission channels have been extensively studied and widely recognized as legitimate, some authors have not refrained from further deepening the understanding of how monetary policy affects the economy. By including a banking sector in the economy and introducing underlying moral hazard and adverse selection problems that prevent markets from being efficient, Bernanke and Gertler, 1995, split the transmission channels in a *balance sheet effect* channel and a *bank lending* channel. The former indicates that there is a wedge between the cost of internal and external finance, the *external finance premium*, which is affected by policy rate changes and works as a financial accelerator. Thus, a contractionary move by the monetary authorities, by decreasing asset prices, may lower firms' value, which deteriorates asymmetric information problems, increasing the premium demanded by banks to concede loans, further decreasing the amount of new projects. The latter, the bank-lending channel (Gertler and Gilchrist, 1993, Kashyap and Stein, 1997, Kashyap and Stein, 2000), works because some agents in the economy can only finance themselves through banks, so an increase in bank reserves and deposits coming from expansionary monetary policy generates more investment, while a contractionary move that reduces banks reserves leads to a decrease in loan supply and a shortcoming in new investment projects. In Cecchetti, 1999, the author builds an argument that shows the importance of this channel, as differences between countries' lending channels lead to disparities in their sensitivity to monetary policy shocks. Furthermore, in this same paper, Cecchetti raises the question of how different legal structures can affect the effectiveness of monetary policy actions. By evaluating the legal and financial structures of pre-Eurozone European Union countries, the author concludes that the impact of different legal structures can be significant in explaining different countries' reactions to monetary policy shocks, which is something that can be further studied and will be slightly addressed in this paper.

More recently, Borio and Zhu, 2012, developed a theory of the *risk-taking* channel of transmission, which the authors define as "the impact of changes in policy rates on either risk perceptions or risk-tolerance". The channel, as argued by Borio and Zhu, incorporates different mechanisms at play: the effect of interest rates on cash flows and incomes, the effect on target rates of return and the effect on risk premia coming from the degree of communication and transparency of the central bank. By incorporating different ways through which it affects the economy, this risk-taking channel can be very important in determining the interest rate that the agents of the economy base their decisions upon, which, as previously mentioned, can differ from the monetary policy one.

The idea of introducing a spread in the consumer interest rate *vis-à-vis* the monetary has already been studied in recent years. Goodfriend and McCallum, 2007, De Fiore and Tristani, 2011, and Cúrdia and Woodford, 2016, do such in the context of simple New-Keynesian models, focusing on how monetary authorities should behave in order to optimize the behavior of their policies given that the relevant consumer rate is not the same as the one set by these institutions. The present paper follows closely this approach, but diverges from the literature by focusing on how the economy reacts to monetary policy shocks versus non-monetary rate shocks while introducing a noisy information structure for consumers, as shown in the following section.

3 The Models

To study the effects of monetary policy news and noise in the macroeconomy, this research follows from Blanchard, L'Huillier, and Lorenzoni, 2013, by building a New-Keynesian model in which consumers have imperfect information regarding the fundamentals of the economy, leading them to imperfectly perceive a monetary policy shock. The microeconomic foundations of the model are found in the appendix, while this section just highlights the necessary equations for understanding the dynamics at play.

First, a simple model is presented, in which consumers do not observe the policy interest rate, observing only a noisy signal on their relevant interest rate, and making decisions based on this. Afterwards, this idea is expanded to a setting in which consumers do observe the monetary policy interest rate, but also receive a noisy signal on the non-monetary policy interest rate that affects their present decision making.

The model makes the relevant consumer interest rate differ from the one set by the central bank. By accepting this, some kind of market imperfection that does not allow for monetary policy to be efficiently transmitted and have the desired effect on output and inflation is being introduced. Hence, this modeling of a non-monetary rate component can be seen as a reduced form of all the non-neoclassical transmission mechanism channels aforementioned, and a shock to this can be intepreted as a friction in the transmission mechanism channel, that improves or deplorates its efficiency, *e.g.* a shock to the external finance premium, to consumer perceptions, financial distress or a shock to the legal strucutre of the economy that affects the agents' intertemporal decision of consumption, but is orthogonal to an unexpected monetary policy shock

3.1 Unobservable Interest Rate

In the present section, a New-Keynesian model is defined in which consumers do not observe the monetary policy interest rate, observing instead a noisy signal on it. The key equations are

$$y_t = E_t[y_{t+1}] - r_t^c + E_t[\pi_{t+1}] \tag{1}$$

$$\pi_t = \tilde{k}(y_t - a_t) + \beta E_t[\pi_{t+1}] \tag{2}$$

$$r_t^M = \chi_\pi \pi_t + q_t \tag{3}$$

Equation 1 represents an IS curve obtained from the households' maximization problem, where $r_t^c = r_t^M + n_t \equiv \chi_\pi \pi_t + s_t$, s_t is the noisy signal on the consumer interest rate and y_t denotes the log deviation of ouput from its long-run potential.

Equation 2 represents a Phillips curve, in which the inflation rate, π_t, depends positively on output and future inflation, and negatively on productivity, here denoted a_t. Here, contrarily to Blanchard, L'Huillier, and Lorenzoni, 2013, there is no distinction between a permanent and temporary component of productivity, instead allowing the productivity level to follow an AR(1) process, which is denoted by $x_t = \rho_x x_{t-1} + \epsilon_t^x$. $\tilde{k}$ represents a non-linear convolution of structural parameters, with $\tilde{k} = (1 + \zeta)(1 - \theta\beta)(1 - \theta)/\theta$, where θ represents the probability of firms not adjusting their prices freely, β is the households' consumption discount rate and ζ represents the inverse Frisch elasticity of substitution in the micro-founded New-Keynesian model.

Lastly, equation 3 represents the Taylor rule through which the monetary authority decides the policy interest rate, r_t^M.

The signal can be defined as

$$s_t = q_t + n_t \tag{4}$$

in which

$$q_t = \rho_q q_{t-1} + \epsilon_t^q$$

$$n_t = \rho_n n_{t-1} + \epsilon_t^n$$

where ϵ_t^q and ϵ_t^n are i.i.d shocks with mean zero and variance σ_q^2 and σ_n^2, respectively.

To find the solution of this model, one needs to understand that it is, in its essence, a signal extraction problem. Consumers, based on their information set, make expectations of the unobserved states using a Kalman Filter, and then, with this in mind, the econometrician estimates the model using the same method.

The Kalman Filter dynamics are

$$X_t = \mathrm{A}X_{t-1} + \mathrm{B}v_t$$

$$S_t = \mathrm{C}X_t + \mathrm{D}v_t$$

where X_t is a vector of unobservables and S_t a vector of observables. In this first model, consumer unobservables are the AR(1) processes of the monetary policy and consumer interest rates, q_t and n_t. Furthermore, it is assumed that consumers observe the productivity level, a_t, and the signal on the consumers interest rate, s_t. A full display of matrices A, B, C and D can be found in the appendix.

It is still needed to solve the imperfect information model in order to formulate the econometrician's problem, which then helps recovering the smoothed states as well as the innovations and impulse responses of our model.

The model, its solution and dynamics are a special case of the more general formulation in Blanchard, L'Huillier, and Lorenzoni, 2013. Let us denote Y_t as a vector of endogenous variables. The economic model presented can be written in terms of Y_t and S_t as

$$\mathrm{F}E_t[Y_{t+1}] + \mathrm{G}Y_t + \mathrm{M}S_t = 0 \tag{5}$$

with the solution

$$Y_t = \mathrm{Q}S_t + \mathrm{R}X_{t|t} \tag{6}$$

As can be observed, in the solution of the model the endogenous variables depend on the behavior of the consumer observables and the retrieved expectations for the unobservable states, here given by $X_{t|t}$. The methods to find matrices Q and R are found in Blanchard, L'Huillier, and Lorenzoni, 2013, and Uhlig, 1995. Furthermore, the dynamics of $X_{t|t}$ are given by

$$X_{t|t} = \text{(I-KC)A}X_{t-1|t-1} + \text{K}S_t \tag{7}$$

where K represents the Kalman gain matrix.

With this, one can thus set up the econometrician's Kalman Filter which includes in its unobservable vector the agents formed expectations of q_t and n_t, $q_{t|t}$ and $n_{t|t}$ repectively. As for the econometrician's observables, we assume they observe the productivity level, a_t, and the endogenous variables y_t, π_t and r_t^M.

3.1.1 Data

The data spans from 1954:Q4 to 2014:Q1, since this corresponds to the earliest available data for the Fed Funds Rate and the latest available for Total Factor Productivity.

The series used for the output, potential output, inflation, the monetary policy interest rate and productivity were, respectively, Real GDP, Real Potential GDP, GDP Implicit Price Deflator, Effective Federal Funds Rate and Total Factor Productivity at Constant National Prices for the United States. All these series were taken from the Federal Reserve Bank of St. Louis' (FRED) online database.

The output gap was calculated as the log deviations of Real GDP from its long-term potential; inflation was obtained by taking the log differences of the GDP Implicit Price Deflator series; the monetary policy rate was obtained by transforming the monthly series available from FRED to a quarterly series; lastly, the Total Factor Productivity series was first differenced and transformed to a quarterly series through Spline interpolation.

3.1.2 Estimation and Results

The parameters of the model were estimated by maximum likelihood. This choice was done to match the empirical exercise done in Blanchard, L'Huillier, and Lorenzoni, 2013, in which the authors conclude that maximum likelihood estimation dominates a method of matching moments, assuming the model is the correct one. Estimating the model with a regular SVAR

Table 1: Maximum Likelihood Estimates

Parameter	Estimate	S.D
θ	0.7166	0.0342
χ_π	1.6572	0.2730
ρ_x	0.9645	0.0205
ρ_q	0.3461	0.0788
ρ_n	0.9311	0.0238
σ_x	0.4344	0.0204
σ_q	0.2487	0.0656
σ_n	0.1539	0.0610
ML	782.2973	

would yield an invertibility problem because the econometrician is not able to separate the transmission mechanism shock from the interest rate one, thus retrieving shocks that are not revealing of the true dynamics of the economy.

The estimation was done by fixing the households' discount rate to 0.99, as done in most literature on this subject. Similarly, the inverse Frisch elasticity was set 2, as this is a value mostly regarded in the literature as reasonable (Blanchard, L'Huillier, and Lorenzoni, 2013, Giannoni and Woodford, 2004, Milani and Treadwell, 2012, Gomes, Iskrev, and Mendicino, 2013, Smets and Wouters, 2007). The remaining parameters were estimated by maximum likelihood using data for the United States as presented in the previous section.

Table 1 shows that the autoregressive processes for the productivity and transmission mechanism shocks are very persistent, which indicates that, in this setting, these two shocks tend to affect the economy for a longer period of time. The assumption of a random walk is not discussed here, as one can just assume that, in this model, there is no permanent shock to the economy, even though this high degree of persistence may be an indication that this could be explored in future research. Also, the estimates for ρ_x and ρ_n may also be explained with the fact that we are only considering three types of shocks, disregarding, for instance, prices and wages innovations.

Figure 1 shows the effects of a one standard deviation shock in the monetary policy interest rate on output and inflation. It is possible to see the low persistence of this shock, as the effect dissipates after more or less five periods for output. This is in line with the widely accepted result that, in a model with nominal rigidities, a shock to the central bank's interest rate affects

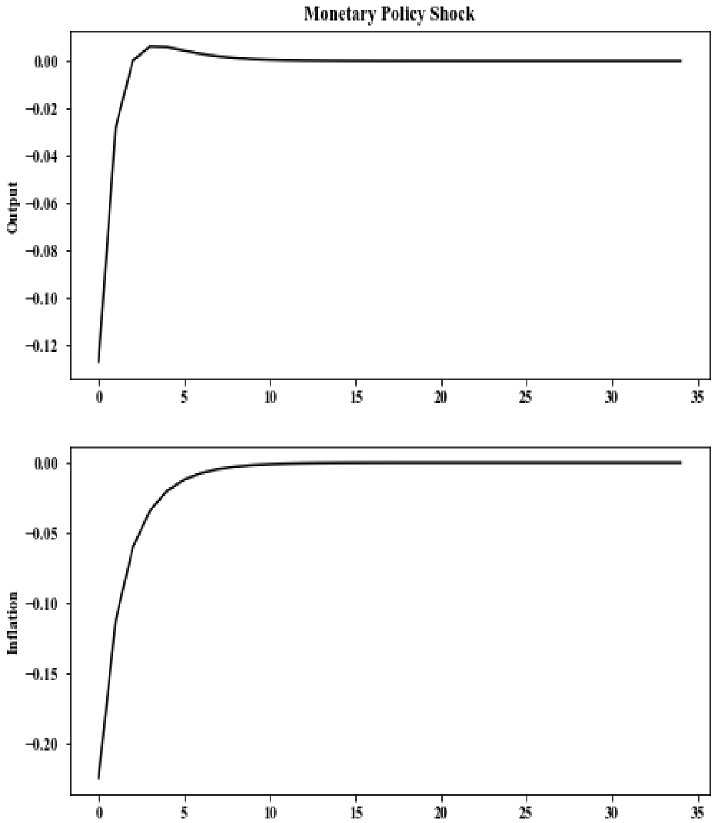

Figure 1: Impulse Responses of a one standard deviation monetary policy rate shock on output (top) and inflation (bottom)

the economy in the short run – as prices do not adjust immediately – but money remains neutral in the long run. The results also show that a positive interest rate shock leads to a negative effect on output and inflation, as expected. Furthermore, prices seem to be more affected by this than output, which could be attributed to a larger degree of price flexibility.

Regarding the effects of the transmission mechanism shock on output and inflation, shown in figure 2, one can see, as expected, that the degree of persistence is much higher than in the monetary policy shock. The interpretation of this depends, of course, on the nature of this shock. As previously stated, in general terms, this is perceived as a shock to the consumer interest rate not channeled through the central bank's interest rate and that reflects the effectiveness of the transmission mechanism. Hence, what the figure shows is that these shocks have a much longer effect on the economy, even though the magnitude is lower than monetary policy ones.

It is possible to think of the policy implications that arise from such results. This analysis shows that a more ineffective transmission mechanism gives birth to long lasting negative repercussions in the economy, as both output and inflation seem to decrease and are slow to

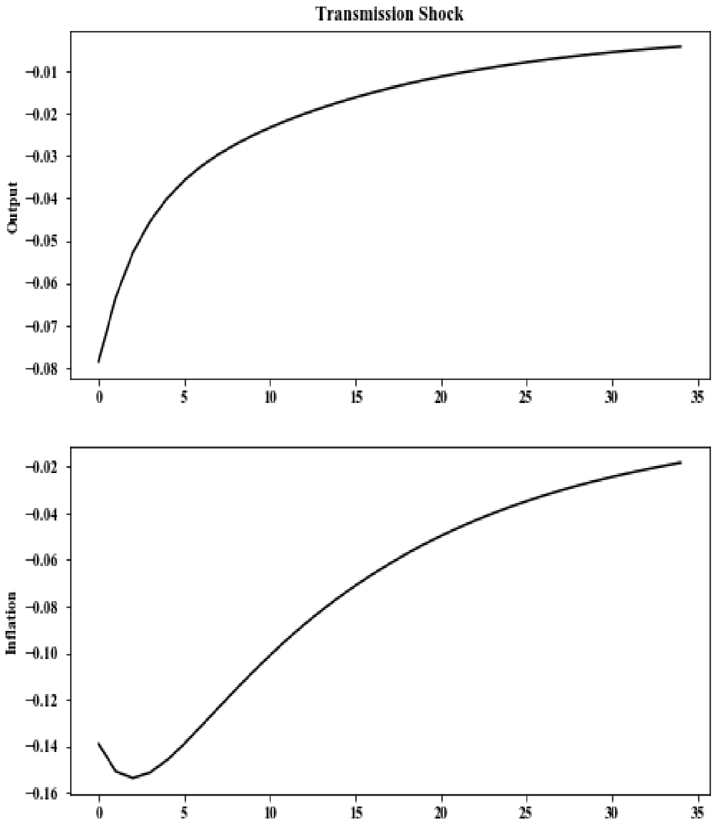

Figure 2: Impulse Responses of a one standard deviation transmission mechanism shock on output and inflation

recover. This could mean that reflections of financial distress or ineffective macroprudential policies have long lasting effects on aggregate variables.

It is also interesting to analyze the importance that each of these shocks has in the economy as a whole by performing a forecast error variance decomposition. This tool helps understanding how much impact a shock has given that all the innovations occur simultaneously. With this, it is be possible to see how important the transmission mechanism shock is *vis-à-vis* the monetary policy shock.

As seen in table 2, the transmission mechanism has, in the long-run, a higher impact on output and inflation when compared with the monetary policy shock, which is what was expected to happen based on the analysis of the IRFs. If, instead, one concentrates on the shorter-term, the results show that the effects of an unexpected shock to the central bank interest rate are more impactful, especially in the first year. However, this impact quickly fades after one year, as it goes from around 7% to 2% for output, and from 71.8% to 43% for inflation.

Overall, the impact of the transmission mechanism shock outweighs the unexpected monetary

Table 2: Forecast Error Variance Decomposition

	Monetary Policy		Transmission Mechanism	
Period	Output	Inflation	Output	Inflation
1	0.0773	0.7180	0.0296	0.2749
4	0.0241	0.4289	0.0214	0.5599
8	0.0140	0.2935	0.0164	0.7395
12	0.0107	0.2458	0.0140	0.7395

policy rule shock. Hence, the consumers' decisions seem to be more affected by changes in the non-monetary policy rate channels, which may indicate that these do reveal important fundamentals about the economy that should not be omitted.

The fact that the econometrician has access to the full dataset, from period 1 to period T, can also be exploited to recover estimates for the unobservable variables using the Kalman smoother. This technique takes advantage of the fact that we can, after performing forward estimation using the Kalman Filter, improve on the estimation by obtaining the states for period T and then proceeding backwards until the first period. Hence, following Hamilton, 1994, the Kalman smoothed estimates for the unobservable variables can be obtained through

$$\hat{X}_{T-1|T} = \hat{X}_{T-1|T-1} + J_{T-1}(\hat{X}_{T|T} - \hat{X}_{T|T-1}) \tag{8}$$

where $J_{T-1} = E\left[(X_{T-1} - \hat{X}_{T-1|T-1})(X_{T-1} - \hat{X}_{T-1|T-1})'\right]A'E\left[(X_T - \hat{X}_{T|T-1})(X_T - X_{T|T-1})'\right]$.

Figure 3 plots, in each panel, the smoothed estimates for the real-time expectations of the agents for the monetary policy interest rate component and for the transmission mechanism component, given by $q_{t|t}$ and $n_{t|t}$, respectively. These are plotted against the econometrician's smoothed estimates for each variable, given by q_t and n_t.

As it can be seen, both the real-time expectations of the agents and the econometrican's estimates follow the same pattern, which can indicate that the model is correctly specified. Furthermore, the monetary policy interest rate component fluctuates much more that the transmission mechanism one. It seems to also have a higher variance up until the 1980's. This may be an indicator of the history of the Federal Reserve's behavior towards monetary policy surprises, as it shows that the rule of the Fed was more erratic until the big rate hikes of the early 80's, a period which saw the U.S suffer with high levels of inflation. From there on, the pattern of surprise monetary shocks seems to be more numb, at least until the Great Recession in the late 2000's. These results are reminiscent of the ones found in Boivin and Giannoni, 2002.

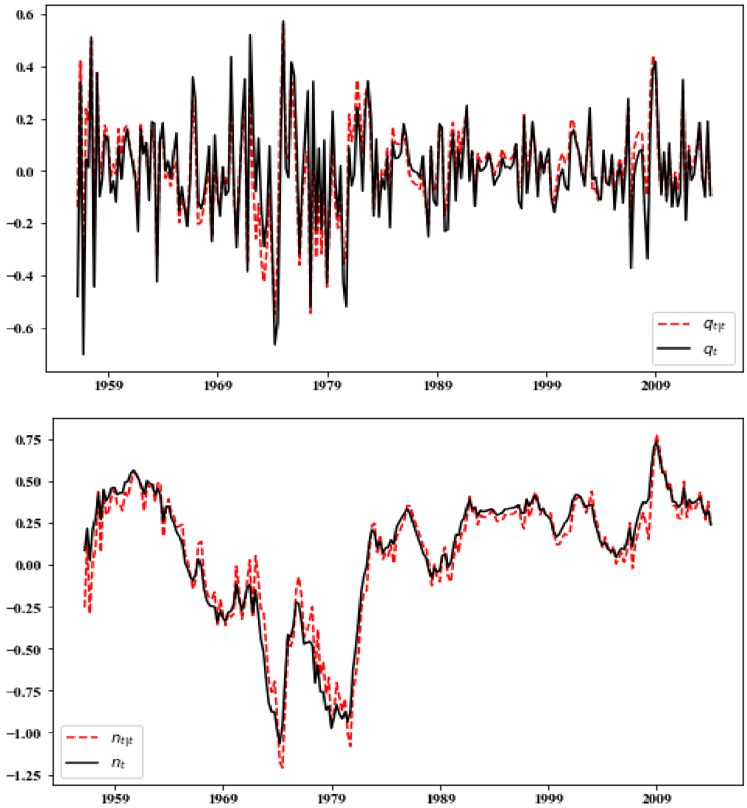

Figure 3: Smoothed Estimates for unobservables

The other component seems to follow, as expected, a more persistent behavior. There is a pattern of negative values for this variable until the rate hikes of Paul Volcker in the 1980's, which is a reflection of a consistent decrease in the agents' interest rate, and may be one of the factors that led to the high inflation of the late 70's. This process is then reversed in the following periods in a regime changing fashion, with the estimates for the unobservable transmission mechanism state accompanying the increase in the monetary policy interest rate. In the following periods, which were characterized by cheap credit and deregulation, we see that the state of the transmisison mechanism fluctates a little above zero, which can be interpreted as a period of low degree of imperfection in the mechanism of monetary policy transmission. The worsening of this state in the late 2000's should be a reflection of the uncertainty and financial distress during the Great Recession.

3.2 A Model With Noise

The previous model presented interesting conclusions regarding how one can look at monetary policy shocks and how the rate of interest for consumers can differ from the monetary authority one. However, it is based on the assumption that the agents of the economy do not observe the monetary policy interest rate, which is somewhat farfetched, although one could argue that the interest rate observed by the agents is not the true rate for the authorities, in which case the previous model becomes more relevant.

Hence, this section will allow for the agents of the economy to observe the true monetary policy rate, r_t^M. On top of this, the model will also be more complex and robust, as to better approximate the dynamics of the model to those of real data (as argued in Giannoni and Woodford, 2004, and Milani and Treadwell, 2012). Thus, the model will introduce internal habit formation in the consumers' decision-making process, inertia in the monetary policy interest rate and a price markup shock, as in Justiniano, Primiceri, and Tambalotti, 2010. Furthermore, the problem of non-invertibility regarding shocks will also be tackled by the introduction a noise component. Noise, as discussed in the literature review, can be a source of econometric instability, as it does not allow the econometrician to estimate true orthogonal shocks. This is also interesting if one believes that most monetary policy related shocks are, nowadays, coming from information frictions, as stated by Ramey, 2016, a scenario in which noise shocks become essential.

The economic interpretation for a noise shock in the context of this model can be derived from different authors' past hypotheses. For instance, if we think of a transmission mechanism shock in the lines of Borio and Zhu, 2012, *i.e.* a shock to the risk-taking channel, then unfounded changes to risk perception can be a source of noise shocks. These behavioral changes do not necessarily reflect a change to the economy's fundamentals, so they should not affect the consumers' decisions. This view of noise shocks is similar to the one in Barsky and Sims, 2012, as the paper analyzes the impact of innovations to consumers' confidence, a concept closely related to animal spirits. On a different perspective, one can think of noise shocks as news about the financial conditions of a banks' borrowers which are not true. This view is tied with the concept of *risk shocks* proposed by Christiano, Motto, and Rostagno, 2014, who find that such shocks are the most important drivers of business cycle activity. Hence, on these grounds, a noise shock could reflect uncertainty and risk that is not underlying in the economy, but still gives way for economic fluctuations, even though small-sized, as will be shown.

The model builds from the one in the previous section, being based on a small New-Keynesian model, with a consumer interest rate that differs from the monetary policy rate. As previously stated, consumers can now observe the monetary policy interest rate, but cannot perfectly observe the transmission mechanism shocks, observing instead a noisy signal, s_t, on them. Hence, the relevant interest rates become

$$r_t^M = \rho_M r_{t-1}^M + (1 - \rho_M)\big(\chi_\pi \pi_t + \chi_y y_t\big) + q_t \tag{9}$$

$$r_t^c = r_t^M + n_t \tag{10}$$

And the noisy signal

$$s_t = n_t + \eta_t \tag{11}$$

The introduction of habit formation allows for current output to depend not only on future variables, but also on past values of output. Hence, the model needs to be re-written by taking this into account

$$\mathrm{F}E_t[Y_{t+1}] + \mathrm{G}Y_t + \mathrm{H}Y_{t-1} + \mathrm{M}S_t = 0 \tag{12}$$

with the solution

$$Y_t = \mathrm{P}Y_{t-1} + \mathrm{Q}S_T + \mathrm{R}X_{t|t} \tag{13}$$

The method to find matrix P can be seen in Uhlig, 1995. Once again, the reader is refered to the appendix to find the foundations and derivations of the model.

3.2.1 Estimation and Results

In Blanchard, L'Huillier, and Lorenzoni, 2013, the authors provide a tool to estimate the imperfect information parameters for more complex models in a simple way. One simply needs to take the equivalent perfect information model, impose a restriction on the shocks' correlation matrix, and obtain the estimated parameters. The authors prove that "the signal extraction model's information structure is equivalent to the information structure of a model with full information and correlated shocks" (see Blanchard, L'Huillier, and Lorenzoni, 2013, Lemma 2),

Table 3: Maximum Likelihood Estimates

	Parameter	Estimate	S.D
h	Habit	0.3992	0.0347
χ_π	MP Inflation	2.0000	0.9314
χ_y	MP Output	0.9706	1.2846
ρ_M	MP Inertia	0.8106	0.0582
AR coefficients			
ρ_x	Productivity	0.7293	0.2281
ρ_q	Monetary Policy	0.2311	0.4664
ρ_n	Transmission Mech.	0.4645	0.1909
ρ_p	Price Markup	0.9269	0.0227
ν_p	Price Markup MA	0.1846	0.0012
Standard Deviations			
σ_x	Productivity	0.3105	0.0044
σ_q	Monetary Policy	0.1243	0.0191
σ_n	Transmission Mech.	0.4500	0.0036
σ_p	Price Markup	0.1594	0.0005
σ_η	Noise	0.1810	0.0043
ML	505.0446		

which makes the estimation of the present model a lot easier, as one needs only to perform the estimation of the full information model with said restriction.

As in the previous section, the model's parameters were obtained by maximum likelihood estimation, apart from the Frisch inverse elasticity of substitution, which was, once again, set to 2, and the Calvo prices parameter, which was set to the value obtained in the previous model, 0.7166. This was done to facilitate convergence of the likelihood function, allowing for the estimation of all the remaining parameters. The full information estimated parameters are described in table 3.

Analyzing these estimates, what can be seen is that now the autoregressive coefficients for the productivity, monetary policy and transmission mechanism residuals are not as persistent as before. This comes down to the additional complexity of the model, as the existence of habit formation and more shocks results in the economy being less dependent of very persistent shocks. As expected, the innovations on productivity and costs are more persistent, consistent with economic theory. The remaining parameters' estimates seem to follow past literature's values (Smets and Wouters, 2007, Justiniano, Primiceri, and Tambalotti, 2010, Blanchard, L'Huillier, and Lorenzoni, 2013), with the exception of the weight of output in the Taylor rule, which is usually lower. This is not very concerning, as the main problem that arises from this is a possible bias of the central bank's decisions towards output stabilization that may not be in line with reality, but should not affect the results in a large degree.

Figure 4 plots the impulse response functions for the shocks of interest in our model. Looking at the effect of an unexpected monetary policy shock, there is a similar pattern to the one in the previous model: a positive monetary policy shock leads to a negative, short-lived effect on both output and inflation. The magnitude of the shock is also similar, being close to -0.15 for both output and inflation, a pattern also seen in the previous section. Hence, even in a more complex model, an unexpected monetary policy disturbance presents the same characteristics, which corroborates the robustness of our findings. It is also in line with the latest views on monetary policy shocks, as previously stated and as seen in Ramey, 2016, that, given today's high degree of central bank transparency and predictability, this type of shock is rare and not very impactful in determining economic fluctuations.

As for the non-monetary policy rate shock, designated as transmission mechanism shock, the economic effects are now somewhat different from what was formerly obtained. Given the lower persistence in the transmission mechanism coefficient, ρ_n, a shock to this component lasts for around 10 periods for output and slightly less for inflation. The initial reaction to such a shock is still negative, being around -0.15 for output (compared to -0.08 in the past model) and -0.08 for inflation (compared to -0.14 previously). However, the negative effect turns positive around period 4. This may come as a rebound effect from the monetary stance of the central bank, as the fall in output and inflation is accompanied by a decrease in the monetary policy interest rates, which in turn positively affects the former variables. This effect could also come from an intertemporal substitution effect, if we think that consumers, facing dire expectations towards the future - hence a higher interest rate given the increase in risk - prefer to delay consumption towards later dates, which is the effect seen around period 5. One interesting results, however, is that inflation seems to pick up faster than output, not reflecting a reaction of prices towards consumption. Hence, the inflation path given the consumers' interest rate shock may be just a reflection of the rebound effect coming from the monetary policy interest rate decrease.

Lastly, looking at how the variables are affected after noise shocks, there seems to be a similar

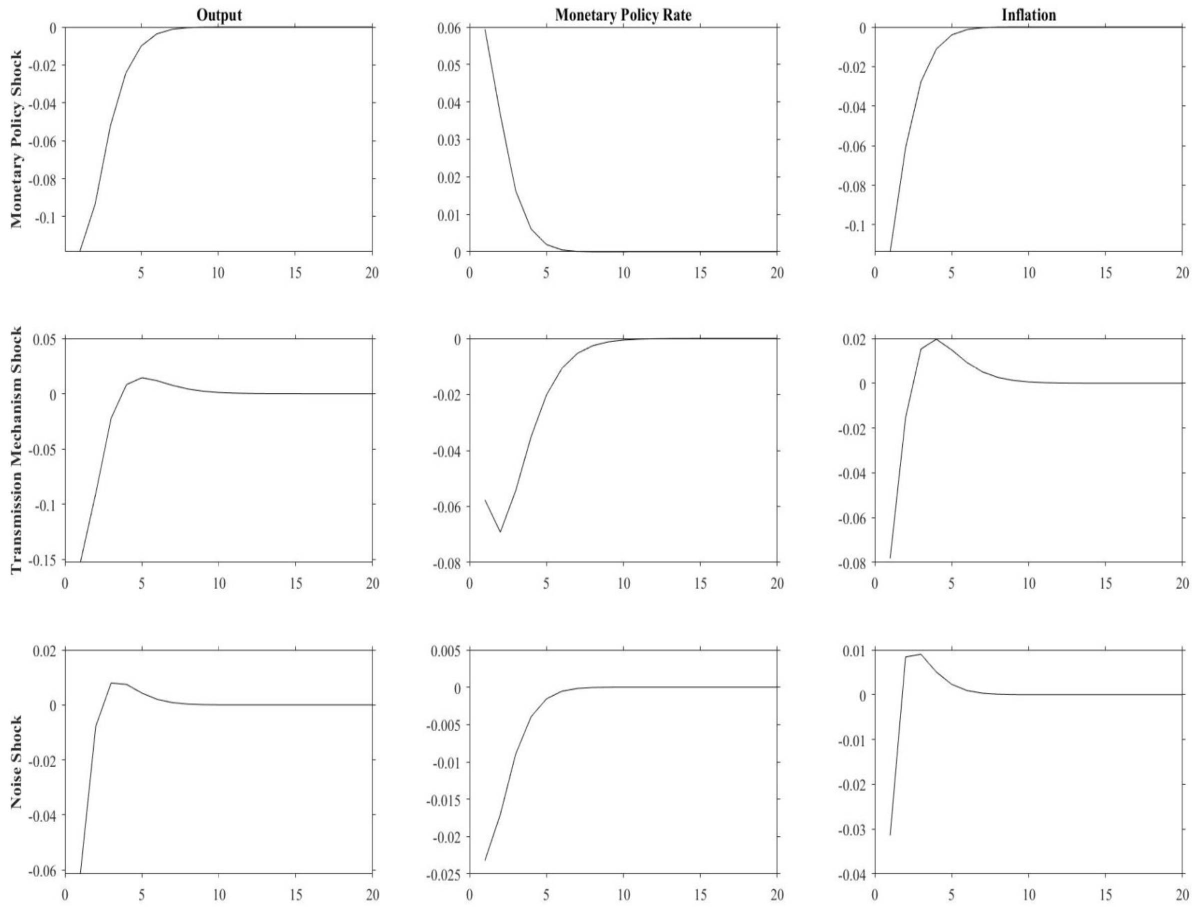

Figure 4: Impulse responses to one standard deviation unexpected monetary policy shock (top line), transmission mechanism shock (middle line), and noise shock (bottom line)

pattern to their transmission mechanism counterparts: there is a negative impact that quickly turns positive. The main differences between these two are the magnitude and persistence, as noise shocks last even less than the others – dying-off at around five periods –, and seem to have a lower impact on the designated variables. A positive one standard-deviation noise shock leads to a negative impact on output of -0.06 in the first period, and of only -0.03 on inflation. This shows that, contrarily to the nature of noise shocks in Blanchard, L'Huillier, and Lorenzoni, 2013, these are not very impactful in the economy, even in the short-run, and can thus maybe be discarded when analyzing similar models.

To further strengthen these results, it is helpful, once again, to analyze the forecast error variance decomposition, as done in the previous model. Table 4 shows that, in a model without investment, the most important drivers of economic activity are productivity and price shocks, as evidenced by the last two columns in the table. It also corroborates the previous finding that

Table 4: Forecast Error Variance Decomposition

Period	MP	Transmission Mech.	Noise	Productivity	Price Markup
Output					
1	0.0564	0.0937	0.0151	0.8086	0.0259
4	0.0468	0.0575	0.0070	0.6415	0.2470
8	0.0353	0.0437	0.0053	0.4993	0.4161
12	0.0312	0.0387	0.0047	0.4429	0.4822
Inflation					
1	0.1123	0.1059	0.0171	0.1582	0.6060
4	0.0306	0.0730	0.0054	0.1527	0.7380
8	0.0188	0.0468	0.0033	0.1153	0.8155
12	0.0157	0.0390	0.0028	0.0976	0.8447

monetary policy shocks are not very impactful in determining output and inflation fluctuations, and also that the transmission mechanism shocks seem to be more important than unexpected monetary policy shocks.

One evident difference between the two models is the decomposition of shocks for inflation. In table 2, inflation was highly affected by both the monetary policy and the transmission mechanism shocks, which is not the case in table 3. This can be a consequence of a better formulation of inflation dynamics by adding the price markup shock as well as habit formation, which perpetuates the effects of a productivity shock on output and, hence, on inflation.

Taking a closer look at the impact of noise shocks, it is also clear that these have a small impact on economic fluctuations. They range from a one percent effect on output and inflation to a 0.4% impact on output and a 0.02% on inflation. This shows that, when explaining interest rate effects on output and inflation, noise shocks are negligible, and do not seem to affect the consumers' decision-making process in a meaningful way.

4 Conclusion

This paper presented two different models that try to discern the effects on output and inflation of unexpected monetary policy shocks against consumer interest rate shocks orthogonal to the former. The narrative constructed here is that there is a part of the transmission mechanism channel that influences consumers' decisions, and that is independent of monetary policy actions. On top of this, informational divergences between the econometrician and the agents are also introduced, similar to Blanchard, L'Huillier, and Lorenzoni, 2013, and Leeper, Walker, and Yang, 2013, to understand how news and information can dictate the behavior of consumers.

The results show that shocks to the transmission mechanism seem to be more impactful and durable than monetary policy innovations, as seen in the first model. If we augment a model to include more realistic dynamics between the variables as well as a noise component to address invertibility problems, the conclusions do not change much: unexpected monetary policy shocks are short-lived and still not very impactful when compared to transmission mechanism shocks. Furthermore, noise shocks do not seem to be particularly relevant to explain aggregate dynamics. These results are, on one hand, good news for central bankers, as the small effect of unexpected monetary policy shocks can be perceived as an increase in the effectiveness of the monetary authorities' transparency and communication; on the other hand, and especially in a context where the central bank is also the macroprudential watchdog of the economy, the conclusions drawn on the consumer interest rate shocks should be seen as a warning, as measures that affect the transmission mechanism of monetary policy can have deeper impacts in the economy. In recent years, macroprudential tools such as imposed capital ratios and buffers on banks can be seen as step towards the reduction of the innefficiencies in the transmission mechanism channels, and are measures that should be drawn with special care.

These results should be further explored, as the models presented are very simple in terms of how they introduce transmission mechanism shocks. There has been some recent work that addresses the effects of these innovations on the economy (Gertler and Kiyotaki, 2010, Brunnermeier and Sannikov, 2014, for instance), but, to the best of our knowledge, none with the informational structure presented in this paper. Thus, it could be interesting to expand the second model into a large-scaled dynamic stochastic general equilibrium model with investment, a banking sector and other financial assets that allowed for the dissection of the effects of different shocks to the consumers' interest rate coming from these different sectors, maintaining a similar informational structure of our proposed model.

5 Appendix

Model Derivation

The model is a particular case of the one in Blanchard, L'Huillier, and Lorenzoni, 2013, where investment is absent, with labor being homogeneous and the only factor of production, flexible wages and no fiscal policy. Furthermore, for the model in section 3.1, the habit parameter, the Taylor rule persistence coefficient and the weight given to output by the monetary authorities are shut down. The equations presented here can also be found in the online appendix of Blanchard, L'Huillier, and Lorenzoni, 2013.

Consumer preferences are given by

$$E\left[\sum_{\infty}^{t=0}\beta^t\left(\log(C_t - hC_{t-1}) - \frac{1}{1+\zeta}N_t^{1+\zeta}\right)\right] \tag{14}$$

where C_t represents consumption at time t, h represent the habits coefficient and N_t labor.

Consumers maximize their utility subject to

$$P_tC_t + B_t = R_{t-1}B_{t-1} + Y_t + W_tN_t \tag{15}$$

where P_t represents the price level, B_t are one period bond holdings, R_t represents the one period nominal interest rate, Y_t the aggregate profits and W_t nominal wage.

Production is given by a continuum of final good producers with the following constant elasticity of substitution function

$$Y_t = \left(\int_0^1 Y_{jt}^{\frac{1}{1+\mu_{pt}}}\right)^{1+\mu_{pt}} \tag{16}$$

$$Y_{jt} = A_tL_{jt} \tag{17}$$

where L_{jt} represents labor services for the production of good j, $A_t = e^{a_t}$ is the productivity term and μ_{pt} is a time varying elasticity of substitution across intermediate goods, Y_{jt}, following the process

$$\log(1+\mu_{pt}) = \log(1+\mu_p) + m_{pt} \tag{18}$$

$$m_{pt} = \rho_p m_{pt-1} + \epsilon_{pt} - \nu_p\epsilon_{pt-1} \tag{19}$$

Intermediate good prices are set in a Calvo setting, with the probability of firms setting their nominal prices being $1 - \theta$.

Market clearing conditions are, thus

$$C_t = Y_t \tag{20}$$

$$\int L_{jt} dj = N_t \tag{21}$$

The full derivation of the optimality conditions and log-linearization of the model can be consulted in the online appendix of Blanchard *et al.*. Here, just the log-linear optimality conditions of the model necessary for the estimation of the model in Dynare are presented. The log-linear optimality conditions for households and firms are

$$\begin{aligned}\hat{\lambda}_t =& \frac{h\beta}{(1-h\beta)(1-h)} E_t \hat{c}_{t+1} - \frac{1+h^2\beta}{(1-h\beta)(1-h)} \hat{c}_t + \frac{h}{(1-h\beta)(1-h)} \hat{c}_{t-1} \\ &+ \frac{h\beta}{(1-h\beta)(1-h)} E_t[\Delta a_{t+1}] - \frac{h}{(1-h\beta)(1-h)} \Delta a_t \end{aligned} \tag{22}$$

$$\hat{\lambda}_t = r_t + E_t\left[\hat{\lambda}_{t+1} - \Delta a_{t+1} - \pi_{t+1}\right] \tag{23}$$

$$m_t = \hat{w}_t \tag{24}$$

where the first two represent the first order conditions for the households' problem, with $\hat{c}_t = \hat{y}_t$ in equilibrium, and m_t represents the log-linear condition for marginal cost. Furthermore, for price settlers, the individual optimality conditions become, in aggregate

$$\pi_t = \beta E_t \pi_{t+1} + \kappa m_t + \kappa m_{pt} \tag{25}$$

where κ is already defined in section 3. Lastly, the wage condition is

$$\hat{w}_t = \zeta l_t - \hat{\lambda}_t \tag{26}$$

where l_t represents the log-linear stationary labor.

Auxiliary Matrices

This section briefly presents the Kalman Filter matrices for sections 3.1 and 3.2. For the former, we have the vector of unobservables, $X_t = \left[q_t, x_t, n_t\right]'$, and the observables $S_t = \left[a_t, s_t\right]'$. The Kalman Filter matrices are

$$A = \begin{bmatrix} \rho_q & 0 & 0 \\ 0 & \rho_x & 0 \\ 0 & 0 & \rho_n \end{bmatrix}, B = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}, C = \begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 1 \end{bmatrix}, D = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

For the model in section 3.2, the unobservables are $X_t = \left[q_t, x_t, n_t\right]'$ and the observables $S_t = \left[a_t, q_t, s_t\right]'$. Notice that q_t appears in both states. This is done just to be able to retrieve the effects of a monetary policy shock when the model is transformed from perfect to imperfect information structure. The matrices of the Kalman Filter become

$$A = \begin{bmatrix} \rho_q & 0 & 0 \\ 0 & \rho_x & 0 \\ 0 & 0 & \rho_n \end{bmatrix}, B = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}, C = \begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 1 & 0 & 1 \end{bmatrix}, D = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

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